

Clan structure analysis and new physics signals in pp collisions at LHC

Alberto Giovannini and Roberto Ugoccioni

Dipartimento di Fisica Teorica, Università di Torino and INFN, Sezione di Torino, via Giuria 1, 10125 Torino, Italy

E-mail: alberto.giovannini@to.infn.it, roberto.ugoccioni@to.infn.it

Abstract. The study of possible new physics signals in global event properties in pp collisions in full phase space and in rapidity intervals accessible at LHC is presented. The main characteristic is the presence of an elbow structure in final charged particle MD's in addition to the shoulder observed at lower c.m. energies.

1. Introduction

The weighted superposition mechanism (WSM) of two properly defined classes of events (or components) explains some experimental facts which altogether characterise collective variables properties in high energy pp collisions and e^+e^- annihilation. In pp collisions the two classes of events are the soft one (without mini-jets) and the semi-hard one (with mini-jets); in e^+e^- annihilation, by using a convenient jet finding algorithm, one distinguishes between two-jet and three-jet samples of events. Let us summarise the mentioned experimental facts [1]:

- 1) shoulder structure in the intermediate n -multiplicity range of the n charged particle multiplicity distribution (MD), P_n , at top c.m. energies and in pseudo-rapidity intervals [1, 2, 3];
- 2) quasi-oscillatory behaviour of the ratio of n -factorial cumulants, K_n , to n -factorial moments, F_n , ($H_n = K_n/F_n$ in the literature) after an initial sharp decrease towards a negative minimum when plotted as a function of the order n at different c.m. energies [1, 4, 5, 6];
- 3) forward (F) — backward (B) multiplicity correlation strength, β_{FB} , energy dependence, with

$$\beta_{FB} = \frac{\langle (n_F - \bar{n}_F)(n_B - \bar{n}_B) \rangle}{[\langle (n_F - \bar{n}_F)^2 \rangle \langle (n_B - \bar{n}_B)^2 \rangle]^{1/2}}, \quad (1)$$

and n_F , n_B the numbers of charged particles lying respectively in the forward and backward hemispheres, and \bar{n}_F and \bar{n}_B their corresponding average charged multiplicities [1, 7, 8, 9].

It should be pointed out that the qualifying assumption of the WSM is that P_n is described for each class of events in terms of the Pascal, i.e., negative binomial (NB), MD with the average charged particle multiplicity, \bar{n} , and k (linked to the variance $D^2 \equiv \langle n^2 \rangle - \bar{n}^2$ by the relation $k = \bar{n}^2/(D^2 - \bar{n})$) as characteristic parameters, and this fact leads to a sound description of the experimental data [1, 10, 11]. The NB (Pascal) MD is well known in high energy physics and has been justified in the framework of QCD. This approximate regularity has been discovered in the seventies in all hadronic collisions in full phase-space in the accelerator and ISR region

[10], then extended by UA5 Collaboration [11] at $p\bar{p}$ collider energies in the eighties to pseudo-rapidity intervals, and systematically studied with success by NA22 Collaboration [12] in pp and $\pi^\pm p$ collisions, by HRS [13] and Tasso [14] Collaborations in e^+e^- annihilation, by EMC Collaboration [15] in deep inelastic scattering and by EHS-RCBC Collaboration [16] in proton-nucleus collisions. These facts led the common wisdom to the conviction that the NB (Pascal) regularity was an approximate general property of all classes of collisions [17], which could be interpreted in the framework of clan structure analysis and understood as a manifestation of a two-step dynamical process [18]: to an initial phase in which clan ancestors are Poissonianly produced, it follows in the second step their decay according to hadronic showers, each described by a logarithmic MD. Each clan contains at least one particle (its ancestor) and all correlations among particles belonging to the same clan are exhausted within the clan itself.

Clan structure parameters are the average number of clans, \bar{N} , and the average number of particles per clan, \bar{n}_c ; these new variables are linked to the standard NB (Pascal) MD parameters, \bar{n} and k , by the following non-trivial relations:

$$\bar{N} = k \ln \left(1 + \frac{\bar{n}}{k} \right) \quad \text{and} \quad \bar{n}_c = \frac{\bar{n}}{\bar{N}}. \quad (2)$$

Suddenly at the end of the eighties it was found again by UA5 Collaboration that the NB (Pascal) regularity did not survive a more accurate analysis at top $p\bar{p}$ collider energies [19]. The violation of the regularity was confirmed at LEP energies in e^+e^- annihilation [20]. Interestingly, the regularity violated in the full sample of events was rediscovered at a more fundamental level of investigation [2], i.e., in the various classes of events contributing to the n charged particle MD of the total sample, P_n^{total} , which accordingly was written as follows:

$$P_n^{\text{total}} = \alpha_1 P_n^{(\text{NB Pascal})}(\bar{n}_1, k_1) + \alpha_2 P_n^{(\text{NB Pascal})}(\bar{n}_2, k_2), \quad (3)$$

with $\alpha_1 + \alpha_2 = 1$. 1 and 2 stand respectively for soft and semi-hard in pp collisions and for 2-jet and 3-jet samples of events in e^+e^- annihilation; α_1 is the weight factor of the first class of events with respect to the total sample. Eq. (3) is one essential ingredient of the WSM. Although our attention will be focused in the following on pp collisions, the WSM is quite general and has been applied successfully also to e^+e^- annihilation. A remark should be added at this point. For a correct description of the FB multiplicity correlation strength, β_{FB} , energy dependence in pp collisions, clans of the same kind of those originally defined on purely statistical grounds are demanded [7]. A result which raises intriguing questions on the real existence of clans themselves as physically observable quantities [21]. In conclusion, clan concept seems more close to the real world than a purely statistical concept.

Accordingly, we decided to examine more carefully clan behaviour in the possible scenarios obtained by extrapolating the weighted superposition mechanism from the GeV to the TeV energy domain [22]. Our search was based on the knowledge of the GeV energy region. Three scenarios were discussed [23]. Following CDF findings at Fermilab it has been assumed that the soft component satisfies KNO scaling in all scenarios, i.e., k_{soft} remains constant throughout all the explored TeV region.

KNO scaling was also assumed for the semi-hard component in the first scenario but being KNO scaling behaviour disfavoured by CDF data [24] between 630 GeV and 1.8 TeV (and it is unlikely to be verified at higher c.m. energies) this possibility was considered quite extreme and not realistic. The semi-hard component is assumed to violate strongly KNO scaling in the second scenario ($k_{\text{semi-hard}}^{-1}$ increases with c.m. energy almost linearly in $\ln s$.) In the third scenario KNO scaling violation is a QCD inspired one, i.e., $k_{\text{semi-hard}}^{-1}$ increases with c.m. energy as $a - b/\sqrt{\ln s}$.

The interest is on the semi-hard component behaviour in the scenario with strong KNO scaling violation (the second one) and in the QCD inspired scenario (the third one) and in their

Table 1. Variation of the average number of clans, $\bar{N}_{\text{semi-hard}}$, and of the average number of particles per clan, $\bar{n}_{c,\text{semi-hard}}$, between 900 and 14 TeV, for the semi-hard component in scenarios II and III.

	$\bar{N}_{\text{semi-hard}}$		$\bar{n}_{c,\text{semi-hard}}$	
	900 GeV	14 TeV	900 GeV	14 TeV
scenario II	23	11	2.5	7
scenario III	22	18	2.6	5

clan structure analysis. The results of this search are given in Table 1. Common feature of both scenarios is the decrease of the average number of clans, $\bar{N}_{\text{semi-hard}}$, and the corresponding increase of the average number of particles per clan, $\bar{n}_{c,\text{semi-hard}}$ as the c.m. energy increases from 900 GeV to 14 TeV. The effect is more pronounced in the second than in the third scenario. It seems that Van der Waals-like cohesive forces are at works among clans. Somehow, clan aggregation is occurring and accordingly particle population density per clan is expected to become larger as c.m. energy increases. This result leads to the following question (See Ref. [25]): when will clan aggregation in the semi-hard component be maximal? Of course when $\bar{N}_{\text{semi-hard}}$ is approximately equal to one unit, i.e., when between the two parameters of the NB (Pascal) MD, $\bar{n}_{\text{semi-hard}}$ and $k_{\text{semi-hard}}$, the following relation holds:

$$\bar{n}_{\text{semi-hard}} = k_{\text{semi-hard}} \left(e^{1/k_{\text{semi-hard}}} - 1 \right). \quad (4)$$

Following the natural decrease of $\bar{N}_{\text{semi-hard}}$ as the c.m. energy increases, relation (4) will be reached at a too high energy to be significant (see Figure 1). Notice that $\bar{N}_{\text{semi-hard}}$ in the first scenario contrary to the other two is growing with c.m. energy: a consequence of $k_{\text{semi-hard}} \simeq \text{constant}$ and the full control of $\bar{N}_{\text{semi-hard}}$ by $\bar{n}_{\text{semi-hard}}$. As already stated, the study of this scenario has been neglected on the basis of CDF findings.

This remark suggests to ask a new question: under which conditions the decrease of the average number of clans to one unit could be extrapolated to 14 TeV? Assuming that these conditions are verified at 14 TeV, are they related to asymptotic properties of the semi-hard component or are they the benchmark of a new class of events, of an effective third component to be added to the soft and semi-hard ones? It should be pointed out that the onset of a third class of events in terms of a second shoulder in P_n vs n is suggested in minimum bias events in full phase-space by Monte Carlo calculations with Pythia version 6.210, with default parameters but using a double Gaussian matter distribution (model 4).

Coming to the first part of the above question, since one is forced to exclude that a sudden decrease of the average number of clans to one unit could be anticipated in the semi-hard component at 14 TeV c.m. energy (it would imply heavy discontinuities in $\bar{n}_{\text{semi-hard}}$ and $k_{\text{semi-hard}}$ general behaviours, a fact which is quite unlikely to occur), it is proposed to consider relation (4) as the benchmark of a new class of events.

Therefore the claim is that

$$\bar{n}_{\text{III}} = k_{\text{III}} \left(e^{1/k_{\text{III}}} - 1 \right) \quad (5)$$

identifies a new class of events (whose onset was foreseen by the aforementioned Pythia Monte Carlo calculations), but with on the average only one clan. Let us examine now the variation domains of the two new parameters \bar{n}_{III} and k_{III} and their influence on the structure of the MD. Since k_{III} parameter increases quickly as the c.m. energy increases and just the opposite

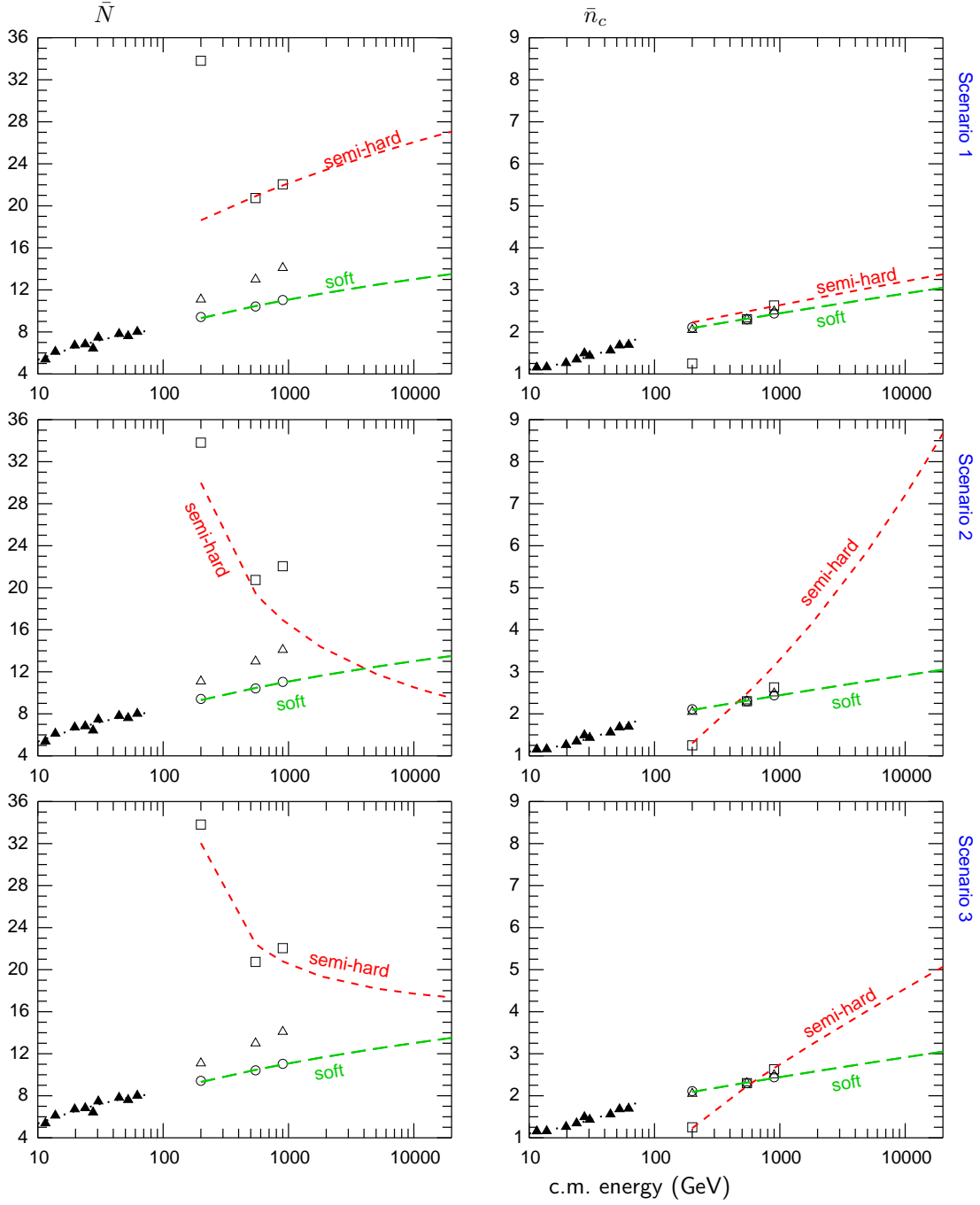


Figure 1. Clan parameters \bar{N} (panels in the left columns) and \bar{n}_c (panels in the right column) are plotted for the scenarios described in the text vs. c.m. energy (from top to bottom: first row: scenario 1; second row: scenario 2; third row: scenario 3). The figures shows experimental data (filled triangles) from ISR and SPS colliders, the UA5 analysis with two NB(Pascal) MD's of SPS data (circles: soft component; squares: semi-hard component), together with our extrapolations (lines: dotted: total distribution; dashed: soft component; short-dashed: semi-hard component)

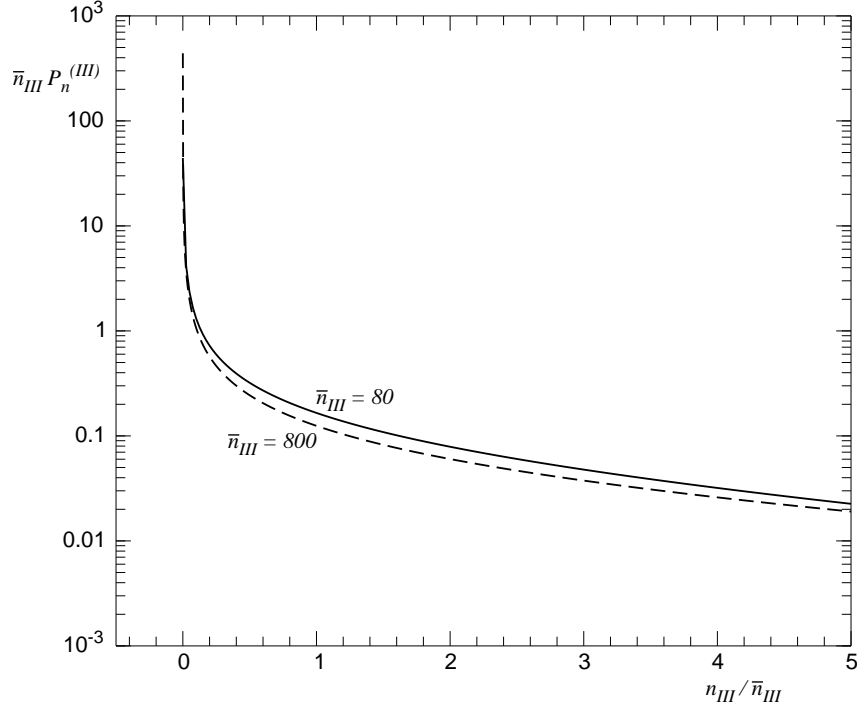


Figure 2. Multiplicity distributions in KNO form for two values of \bar{n}_{III} , with the respective values of k_{III} (0.1611 for $\bar{n}_{III} = 80$ and 0.1128 for $\bar{n}_{III} = 800$) obtained from Eq. (5), i.e., requiring $\bar{N}_{III} = 1$.

happens to \bar{n}_{III} , at 14 TeV one should expect that $\bar{n}_{III} \gg k_{III}$. This condition implies that the NB (Pascal) MD of the third component becomes a gamma MD. In addition, being \bar{N}_{III} reduced to one unit, one should expect that single clan MD should be quite well approximated by a logarithmic MD, according to the general rule of clan structure analysis. This requests implies that $k_{III} \rightarrow 0$. The gamma MD for the single clan for $k_{III} < 1$ is indeed a log-convex distribution, which for $k_{III} \ll 1$ and close to zero is well approximated by the wanted logarithmic MD. Altogether, the above conditions

$$\bar{n}_{III} \gg k_{III} \quad k_{III} \ll 1 \quad \text{and} \quad \simeq 0$$

clarify in terms of standard NB (Pascal) MD parameters the deep meaning of relation (5) for $\bar{N}_{III} \simeq 1$.

2. Main properties of the new class of events

2.1. $P_n^{(III)}$, the n charged particle MD

Coming to the n charged particle MD of the third class of events, $P_n^{(III)}$, the plot in Figure 2 of $\bar{n}_{III} P_n^{(III)}$ vs n_{III}/\bar{n}_{III} reveals for $n_{III}/\bar{n}_{III} < 1$ quite large values of $\bar{n}_{III} P_n^{(III)}$ (events with low multiplicity with respect to \bar{n}_{III} are more numerous); a result which should be compared with the behaviour of $\bar{n}_{III} P_n^{(III)}$ in the region $n_{III}/\bar{n}_{III} > 1$: here events with high multiplicity with respect to \bar{n}_{III} are less probable although they extend for very large multiplicities.

2.2. Two-particle correlations

Two-particle correlations of the new component,

$$\frac{\bar{n}_{\text{III}}^2}{k_{\text{III}}} = \int C_2^{(\text{III})}(\eta_1, \eta_2) d\eta_1 d\eta_2 \gg \frac{\bar{n}_{\text{semi-hard}}^2}{k_{\text{semi-hard}}}, \quad (6)$$

are much larger than two-particle correlations of the semi-hard component.

2.3. n -factorial cumulant moments, $K_n^{(\text{III})}$

Since k_{III}^{-1} controls n -factorial cumulant moments behaviour at any order n for the NB (Pascal) MD and for its limits in \bar{n}_{III} and k_{III} parameters, $K_n^{(\text{III})}$ is expected to be much larger than $K_n^{(\text{semi-hard})}$.

2.4. Saturation of FB multiplicity correlation strength, β_{FB}

In $b_{\text{III}} \equiv \bar{n}_{\text{III}}/(\bar{n}_{\text{III}} + k_{\text{III}})$, being $\bar{n}_{\text{III}} \gg k_{\text{III}}$, with $k_{\text{III}} \rightarrow 0$ one should have $b_{\text{III}} \rightarrow 1$ and since for $\bar{N}_{\text{III}} \rightarrow 1$ the corresponding leakage controlling FB multiplicity correlations close to its maximum (leakage parameter close to 1/2) one gets:

$$\beta_{FB, \text{III}} = \frac{2b_{\text{III}}p_{\text{III}}(1 - p_{\text{III}})}{1 - 2b_{\text{III}}p_{\text{III}}(1 - p_{\text{III}})} \rightarrow 1, \quad (7)$$

i.e., $\beta_{FB, \text{III}}$ saturates and FB multiplicity correlations in the third component are much stronger than in the semi-hard class of events. An indication, in view of the extremely high virtuality and hardness of these events, of a huge colour exchange process at parton level of which strong FB multiplicity correlations are presumably the hadronic signature.

In conclusion, in this framework one should expect to see at 14 TeV in pp collisions three classes of events each one described by NB (Pascal) MD or by its limiting values:

- i) the class of soft events with k_{soft} constant as the c.m. energy increases;
- ii) the class of semi-hard events with $k_{\text{semi-hard}}$ which decreases as the c.m. energy increases (the class of events of the first scenario has been excluded by CDF findings);
- iii) the class of hard events with $\bar{n}_{\text{III}} \gg k_{\text{III}}$ and $0 \lesssim k_{\text{III}} \ll 1$, i.e., $\bar{N}_{\text{III}} \simeq 1$

The total n charged particle MD P_n^{total} should therefore be written as follows:

$$\begin{aligned} P_n^{(\text{total})} &= \alpha_{\text{soft}} P_n^{(\text{NB Pascal})}(\bar{n}_{\text{soft}}, k_{\text{soft}}) \\ &+ \alpha_{\text{semi-hard}} P_n^{(\text{NB Pascal})}(\bar{n}_{\text{semi-hard}}, k_{\text{semi-hard}}) \\ &+ \alpha_{\text{III}} P_n^{(\text{NB Pascal})}(\bar{n}_{\text{III}}, k_{\text{III}}), \end{aligned} \quad (8)$$

with $\alpha_{\text{soft}} + \alpha_{\text{semi-hard}} + \alpha_{\text{III}} = 1$, where α_{soft} , $\alpha_{\text{semi-hard}}$ and α_{III} are the weight factors of the three classes of events with respect to the total sample of events (See Figure 3).

Assuming that at 14 TeV the third class of events is 2% of the total sample of events and that $k_{\text{III}} \simeq 0.12$ and extrapolating α_{soft} and $\alpha_{\text{semi-hard}}$ from their behaviour in the GeV energy range [23] one gets in full phase-space (FPS) the numbers in Table 2 (notice that small variations of k_{III} below 0.12 in Equation (5) give $\bar{n}_{\text{III}} \gg 460$.)

In the pseudo-rapidity interval $|\eta| < 0.9$, assuming (1) that the clan is spread over all the phase-space or (2) concentrated in $|\eta| < 0.9$ one gets the results in Table 3.

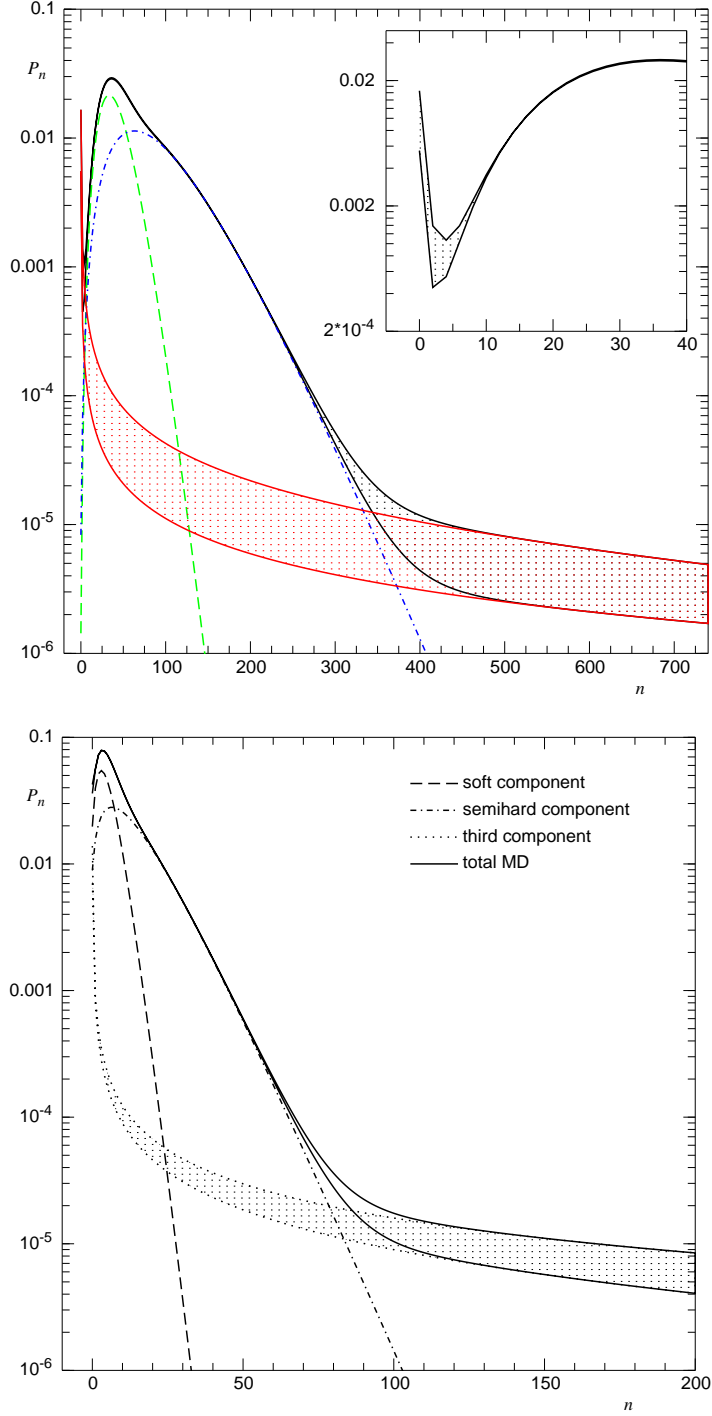


Figure 3. n charged particle multiplicity distribution $P_n^{(\text{total})}$ (solid line) expected at 14 TeV in full phase-space (top panel) and in $|\eta| < 0.9$ (bottom panel) in presence of a third (maybe hard) component with $\bar{N}_{\text{III}} = 1$, showing one shoulder structure and one ‘elbow’ structure; the three components are also shown: soft (dashed line), semi-hard (dash-dotted line) and the third one (dotted band).

Table 2. Parameters of the three components at 14 TeV in full phase-space.

FPS	%	\bar{n}	k	\bar{N}	\bar{n}_c
soft	41	40	7.0	13.3	3.0
semi-hard	57	87	3.7	11.8	7.4
third	2	460	0.12	1	460

Table 3. Parameters of the three components at 14 TeV in the pseudo-rapidity interval $|\eta| < 0.9$.

$ \eta < 0.9$	%	\bar{n}	k	\bar{N}	\bar{n}_c
soft	41	4.9	3.4	3.0	1.6
semi-hard	57	14	2.0	4.2	3.4
third (1)	2	40	0.06	0.37	109
third (2)	2	460	0.12	1	460

3. Conclusions

The reduction of $\bar{N}_{\text{semi-hard}}$ in pp collisions with the increase of the c.m. energy in the TeV energy region (second and third scenarios discussed in [23]) led us to postulate a third class of hard events to be added to the soft and semi-hard ones, whose benchmark is $\bar{N}_{\text{III}} \simeq 1$, i.e., $\bar{n}_{\text{III}} \gg k_{\text{III}}$ and $k_{\text{III}} \ll 1$ with $k_{\text{III}} \simeq 0$.

The main properties of this new class of events are discussed and predictions at LHC are presented.

The extension of this search to nucleus-nucleus collisions is under investigation.

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